Triggering of a mechanically supported breath

By Alex Yartsev - 16/06/2015
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The trigger phase variable determines how a mechanical breath is initiated. This variable determines whether a mode of ventilation can be described as "mandatory" or "spontaneous". Historically, this has been a purely machine-driven affair – but with advent of microprocessor-controlled ventilators, mechanical ventilation has become more user friendly (where the user is the patient). Patient-triggered modes are generally more comfortable, and can improve the work of breathing.

From an exam point of view, it is hard to fit this topic into the domain of the CICM primary, mainly because there is no room for it in the 2023 CICM Primary Syllabus. It remains in this position because of the authors obstinate insistence on the importance of this knowledge to the junior trainee at the beginning of their training. Though the college does not appear to share this view, their mid-training WCA competency "Ventilation" includes "describes methods of triggering and cycling in spontaneous ventilation" as one of the performance criteria. Moreover, of the past paper questions regarding triggering, there have been some notable Part II questions about this variable: Question 18 from the second paper of 2015 and Question 11.1 from the second paper of 2017 both asked for some detailed information on these topics (at least as much as would be expected from a ten-minute exam answer). The author assumes that at Fellowship exam-level the trainees already have a firm grasp of these matters, and in the Part II required reading section mechanisms of ventilator breath triggering are dealt with in a very condensed and heavily redacted format, suitable for rapid revision.

In summary:

- The trigger phase of mechanical ventilation is defined by the transition from expiration to inspiration
- The trigger variable determines when this transition occurs
- There are serval methods of triggering, each of which have advantages and disadvantages:

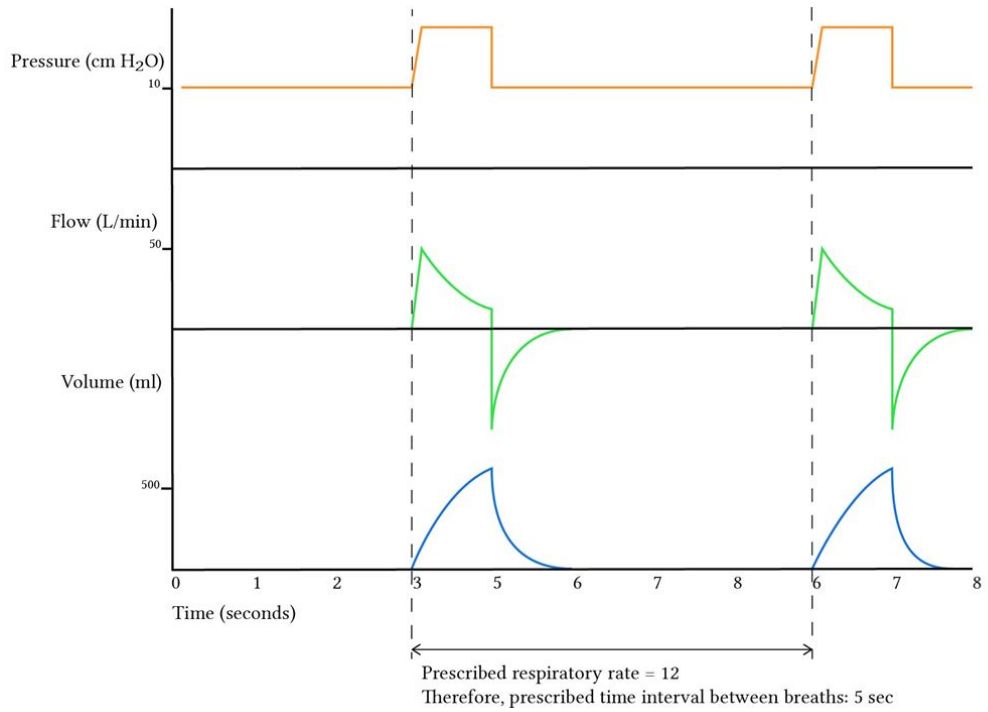
- **Time triggering** which guarantees a minute volume and decreased work of breathing but which is less comfortable
- **Pressure triggering** which gives the patient more control over the initiation of a breath, but which can also be uncomfortable
- **Flow triggering** which is the most comfortable but which can be over-sensitive, leading to dyssynchrony
- **Shape-signal triggering** which may decrease wasted effort by "predicting" the next respiratory effort, and which is not widely available
- **Neural assist (NAVA) triggering** which is theoretically the most effective but which is practically difficult to maintain, and which does not have strong evidence to back it
- **Volume-triggering,** which requires the patient to decrease the volume in the circuit – this is virtually unknown

- Of these, time pressure and flow triggers are the most common.
- Flow triggering is favoured as the best choice for spontaneously breathing patients because of some (low quality) evidence in support of its positive effect on ICU stay and duration of ventilator weaning

In terms of wider reading on this topic, there is plentiful information in the free article by Catherine Sassoon (2011). One should not need to read more broadly than that for the purposes of exam preparation. Having constructed this summary, one must reluctantly acknowledge that there is probably little merit in pursuing this topic to the level of detail presented below, and that it is perfectly possible to complete one's training in intensive care medicine and then have a fruitful career without being even vaguely aware of any of these minutiae.

Time-triggered ventilation

When a ventilator is set to time-triggered ventilation, it will measure a period of time since the last expiration and then deliver a breath. For instance, when a respiratory rate of 12 has been set, the ventilator will deliver inspiratory flow exactly every five seconds. Such breaths are characterised as "mandatory", implying that the patient has no choice in the matter. This is what determines whether one's mode of ventilation is mandatory or spontaneous; a time-triggered mode is always mandatory. All the other trigger mechanisms permit the patient to have some control over the timing of inspiration.



This was the default setting in earlier ventilator models which did not permit the patient to take breaths beyond the set rate. Most modern ventilators allow patient triggering, and take some effort to synchronise their mandatory breaths with patient effort. Synchronised intermittent mandatory ventilation or SIMV is discussed in greater detail in a later section of this learning module.

Without digressing into a discussion of the advantages and disadvantages of spontaneous and mandatory modes of ventilation, it will suffice to say that time-triggering has its merits.:

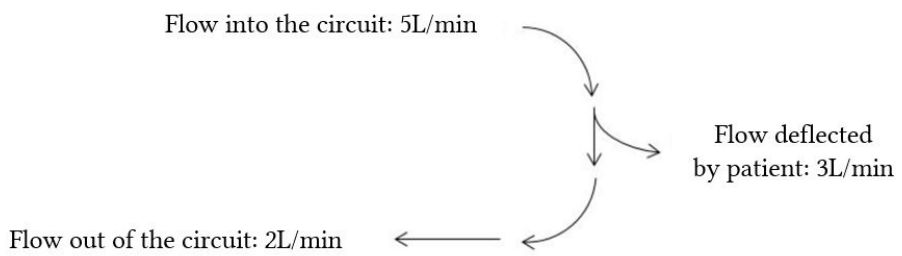
- There is a guaranteed respiratory rate for patients who are … insufficiently interested in breathing
- The guaranteed minute volume offers predictable CO2 removal
- There is no increased patient effort wasted on triggering the ventilator

There are also some drawbacks:

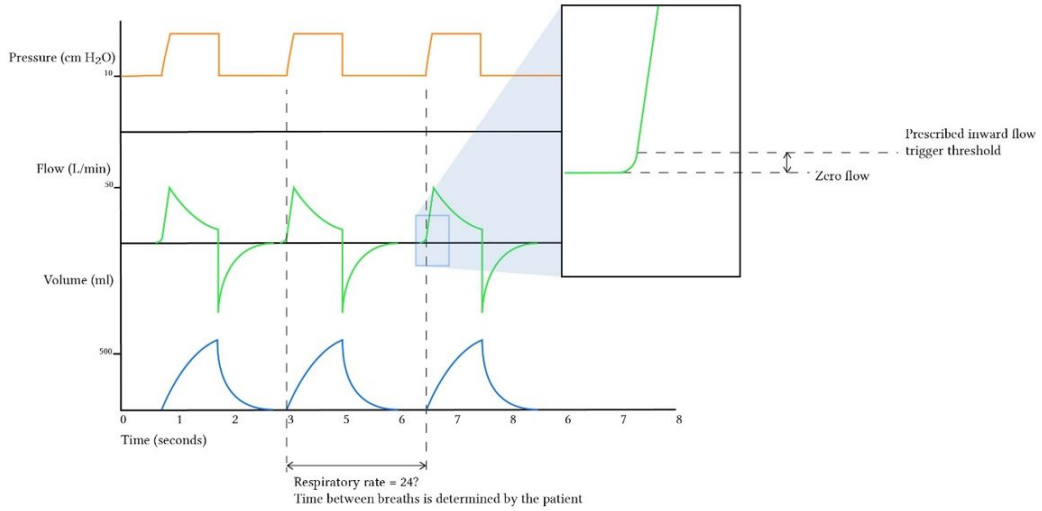
- It may be uncomfortable
- The sedation requirements are likely going to be higher
- It may lead to deconditioning

Flow-triggered ventilation

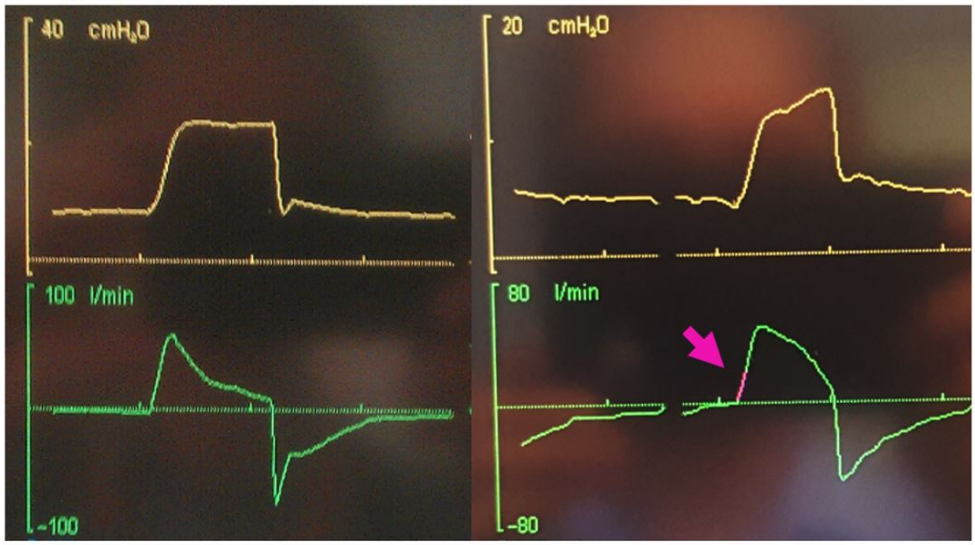
The flow trigger is the most commonly used form of triggering for spontaneous modes ventilation, as creating a small inward flow is a convenient low-effort way for the patient to notify the ventilator of the fact that they want a breath. This is possible because the ventilator circuit has a constant bias flow going through it during the expiratory phase, which is usually low enough not to be wasteful of gas. In the SERVO-i model this flow is around 2 litres per minute. In order to trigger the ventilator, the patient needs to deflect some of this bias flow, so that the expiratory flow sensor and the inspiratory flow sensors detect a difference between inspiratory (Vin) and expiratory (Vout) flow rates. In the absence of respiratory effort (or significant leak), the circuit has intact bias flow such that Vin - Vout = 0 (i.e all of the flow is "accounted for").



When a patient takes a breath, some of the flow is directed into their lungs. The expiratory flow rate in the ventilator circuit is decreased by this, such that Vin - Vout = x, where x is some "missing" flow measured in L/min. Flow triggering occurs when this missing flow reaches some prescribed threshold value, which causes the ventilator to open the inspiratory valve and deliver a breath. The exact value is susceptible to manipulation via the settings, and the default setting differs between manufacturers, but generally it's in the ballpark of 1-2 L/min. For comparison, the normal mean inspiratory flow rate at rest is probably about 15L/min, with a peak of around 30-35L/min (Tobin et al, 1983) which makes this a relatively effortless goal to achieve.



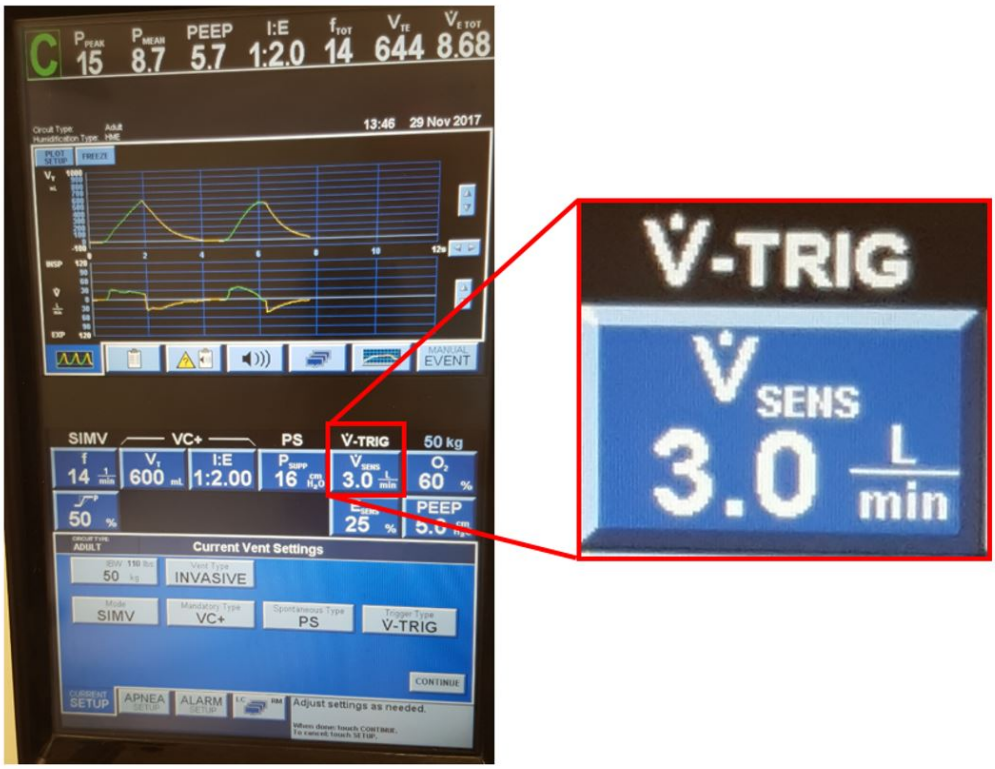
In general, the ventilator will also alert you to the fact that the patient made a spontaneous respiratory effort, eg. by colouring the waveform. For example, the SERVO-i model makes the flow waveform pink.



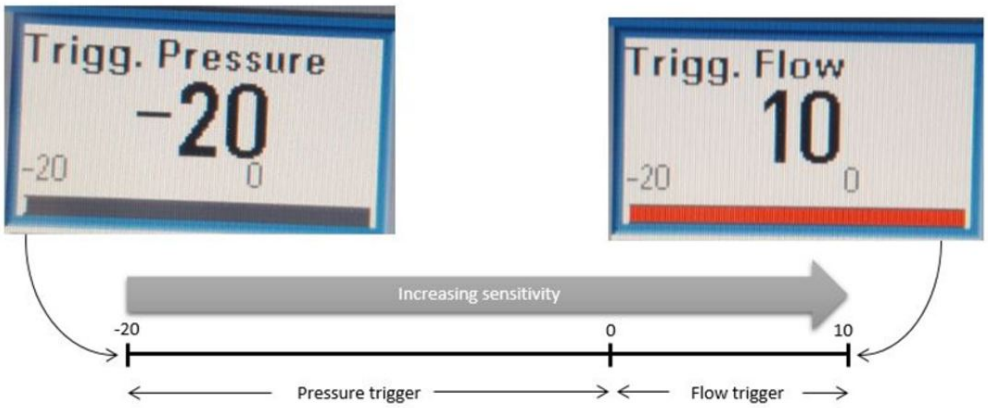
Mandatory breath

Patient-triggered breath

Interestingly, the flow trigger setting should probably be in litres per minute (that, after all, is how we measure flow) but this is not viewed as mandatory by all ventilator manufacturers. For instance, the Puritan Bennett 840 allows the user to set a flow trigger directly, in L/min. In the case below the trigger is set to 3L/min.



Thus, in the Puritan Bennett models, setting a lower value of flow trigger (eg. 2L/min or 1L/min) represents an increase in sensitivity, i.e. a lower flow required to trigger a mechanical breath. In contrast, in the Maquet SERVO-i model interface, a decreasing trigger value corresponds to a *decrease* in sensitivity. Their trigger variable is controlled by the twiddly dial on the ventilator and can be tuned to a range of settings from -20 to +10. This range represents an increasing sensitivity of the trigger, from least sensitive at -20 to most sensitive at 10.



To make things more confusing, the range between -20 and 0 actually represents a pressure trigger; the values in this range correspond to a negative

pressure in cm H_2O, such that a setting of -20 represents a pressure trigger of -20 cm H_2O. The range between 0 and 10 represents a flow trigger, and corresponds to a percentage of the bias flow which needs to be "deflected" by the patient in order to trigger the mechanical breath. A setting of 0 is the least sensitive flow trigger, and represents a 100% deflection (i.e. the patient must generate a flow equal to 100% of the bias flow though the circuit, or 2L/min). A trigger of 10 is the most sensitive, and represents a flow deflection close to 1% of the bias flow. The default setting of a recently reset/restarted SERVO-i ventilator is a flow trigger of 5, which corresponds to a bias flow change of 50%, or 1L/min. It would be wonderful if these things were made obvious to the user, but in fact one needs to dig through the SERVO-i service manual to find such information.

As already mentioned, flow triggering is used on most modern ventilators as the default trigger variable for all spontaneous modes of ventilation. Again, without digressing extensively on the merits and demerits of spontaneous ventilation, it will suffice to summarise its advantages:

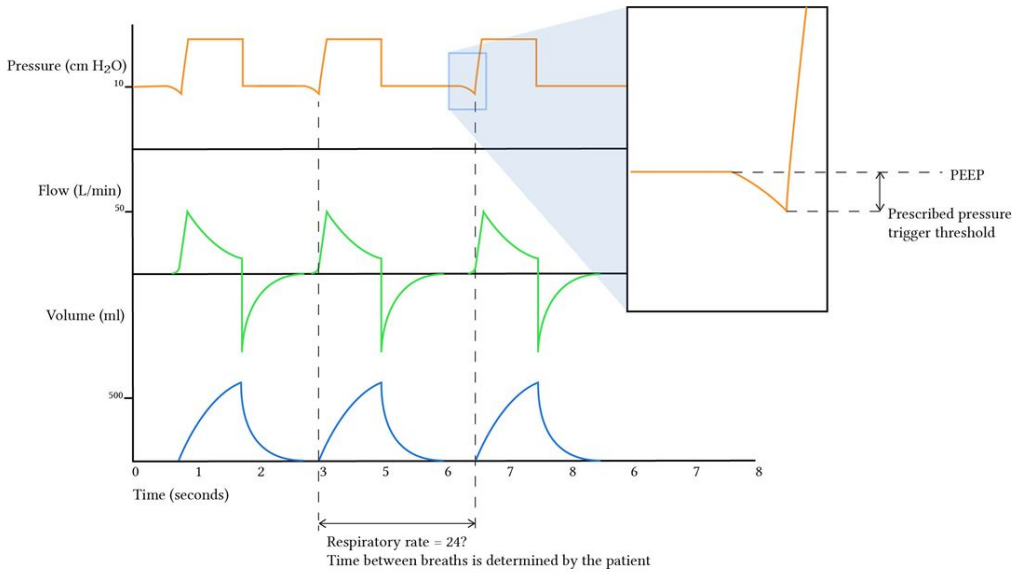
- It is quite sensitive; i.e. little patient effort is required to trigger a mechanical breath, and therefore the patient's work of breathing is not "wasted" on triggering the ventilator.
- It allows the patient to have control over their minute volume, which prevents dyssynchrony due to unsatisfied respiratory drive
- Work of breathing may be decreased.
- It is more comfortable because of a decreased work of breathing in triggering, increased control over ventilation and also because the triggering occurs with less delay, so that the initiation of a breath by the patient is rapidly translated into a mechanical breath.
- It permits a lower level of sedation because it is more comfortable.
- It may reduce patient-ventilator dyssynchrony particularly when the dyssynchrony is due to wasted effort (eg. an insufficiently sensitive trigger)
- As the result of all these benefits, flow triggering permits earlier extubation according to a study by Khalil et al (2015). Less sedation probably plays a major role in this.

There are also some problems with flow triggering:

- It may be too sensitive, giving rise to auto-triggering (a form of dyssynchrony where non-respiratory influences on circuit flow trigger mechanical breaths; for example, the cardiac pulsation, fluid in the circuit, secretions in the airway, etc). In these cases, a pressure trigger may be better (that's probably one of the only uses of a pressure trigger).
- It does not guarantee a minute volume, which means it is unsuitable for patients with a diminished or unreliable respiratory drive. Fortunately, most ventilators come with a backup mode which automatically starts a mandatory breath rate if the patient decided to be apnoeic for some sustained period of time.

Pressure triggering

Pressure triggering describes a method whereby a decrease in circuit pressure is detected by the ventilator pressure sensors and interpreted as patient effort. The patient inhales against a close inspiratory valve, producing a pressure drop by this effort, and in response, the ventilator delivers a mechanical breath by opening the inspiratory valve. Conventionally, where a pressure trigger is used for a prolonged period, a typical setting would be 1 cm H_2O.



This is very old-school. In the 21st century pressure triggering is seldom used in routine mechanical ventilation, but back in the day it was the only method

of giving patients any control over their respiratory rate, and the main reason for this was technological.

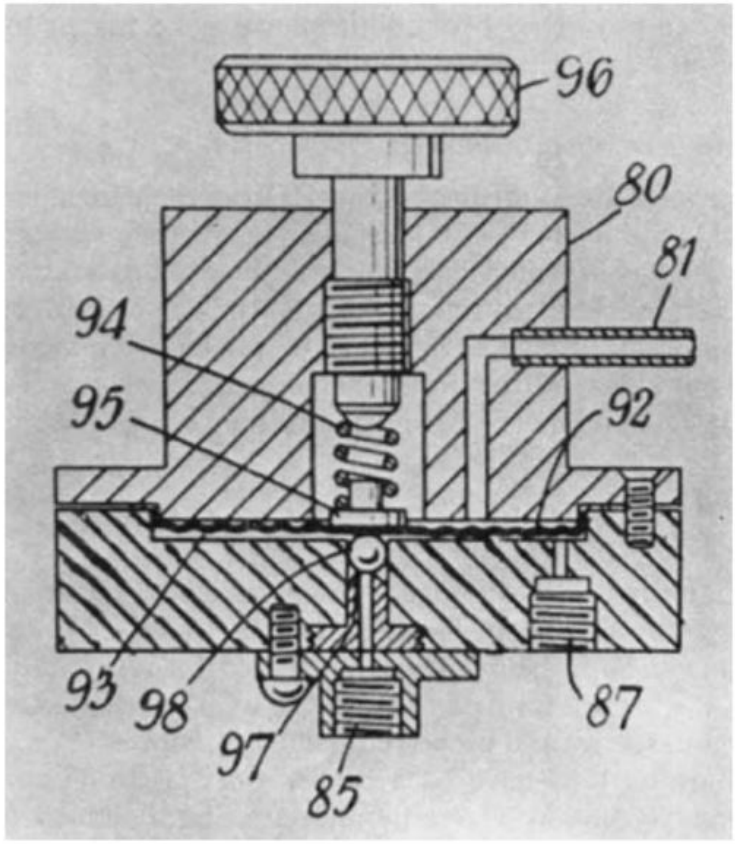


FIGURE 9 The mechanism of the trigger sensing unit

Miniaturised aneroid manometers were expensive, drifted from calibration and required servicing. Instead, pressure sensors were coupled into the actual inspiratory valve mechanism in various ingenious ways. An excellent example of an early application of this positive pressure triggering is described by Geoffrey Burchell (1965), and the image to the left is also misappropriated from his excellent paper. The schematic describes the mechanism of the pressure trigger sensing unit, which was a purely mechanical device. In essence, it is a valve where a slight negative pressure in the circuit snaps open the compressed gas supply regulator, thereby delivering the mechanical breath. The knob on the top (96) can be twisted to adjust the tension on the spring, thereby increasing or decreasing the sensitivity of this trigger.

Though the exact mechanism doubtlessly became more sophisticated with the years, the combination of instrument cost and corporate inertia produced an environment in which these technologies persisted until relatively recently. Writing in 1997, Nava et al complained that of the commercially available

models of non-invasive ventilators, only 28% were equipped with flow-triggering capabilities. The rest were set to trigger at 1.0 cmH_2O.

Why that pressure? Among the desirable characteristics for a ventilator, Burchell listed a pressure trigger capable of sensing negative pressure in the range of around 1 cm H2O, and ideally below. It was felt that this represented some sort of sensible compromise between patient comfort and synchrony-wrecking oversensitivity. However, though it is relatively small, a 1cm H2O pressure trigger still represents a non-trivial workload. Banner et al (1993) demonstrated a significantly increased respiratory workload with pressure triggering, as compared to flow triggering. Where intrathoracic pressure is already high (eg. where there is auto-PEEP) this effect is probably exaggerated. Nava et al had mainly COPD patients in their study and found that the work of breathing was increased by about 20% with pressure triggering. This makes sense, as no inspiratory flow is generated while the patient is inhaling against a closed inspiratory valve; this wasted effort could be viewed as counterproductive wherever the main objective of mechanical ventilation is to reduce the work of breathing.

These problems have implications for patient comfort. Apart from the increased work of breathing, it is felt that the experience of pressure-triggered mechanical ventilation is rendered much more frustrating by a delay between trigger effort and breath initiation. In that scenario, there is a period of time between the initiation of respiratory effort and the opening of the inspiratory valve during which the patient is essentially choking (inhaling against an obstructed respiratory circuit).

In summary, the disadvantages of pressure triggering are:

- It requires more effort to trigger the ventilator, as a change in pressure of even -1cm H2O requires more patient effort than a change in flow
- It represents a wasted respiratory effort, as no inspiratory flow is generated while the patient is inhaling against a closed inspiratory valve; this wasted effort may be counterproductive when the main objective of mechanical ventilation is to reduce the work of breathing
- It is less comfortable for the patient
- It may result in increased sedation requirements because of the above factors, which may be counterproductive in the course of ventilator

weaning

So, in a modern ventilator, what's the use of this option? Surely if flow triggering is so good you would just use that as a default? Well. There are some scenarios which make a good case for the use of a pressure trigger.

- It can be used to decrease auto-triggering, for instance by a circuit leak, bronchopleural fistula or a hyperdynamic circulation. Decreasing the trigger sensitivity could prevent the inappropriate triggering of breaths by these non-respiratory stimuli. In this case, the inappropriately triggered breaths lead to *more* wasted respiratory effort, because the patient does not want them and will actively resist them (sedation requirements also tend to increase). Paradoxically, a more "stiff" trigger setting will actually improve patient-ventilator synchrony in this scenario.
- It can be used to test the power of respiratory musculature, in the context of an assessment of readiness for extubation. A patient who is able to trigger the ventilator by generating a negative intrathoracic pressure of -20 cm H2O is unlikely to fail extubation due to the weakness of their respiratory muscles.

Comparison of pressure triggering and flow triggering

You have the option of both. Is one really better, all other things being equal? Outside of special use cases, one probably has the choice of either, and which one chooses does not seem to matter in the short term. A representative study is this trial by Tutuncu et al (1997), where sixteen ventilated patients underwent several changes to triggering conditions (pressure trigger of 1.0 cm H_2O, flow triggers ranging from 0.7 to 2.0 L/min) and found absolutely no difference in short-term gas exchange respiratory mechanics or inspiratory workload.

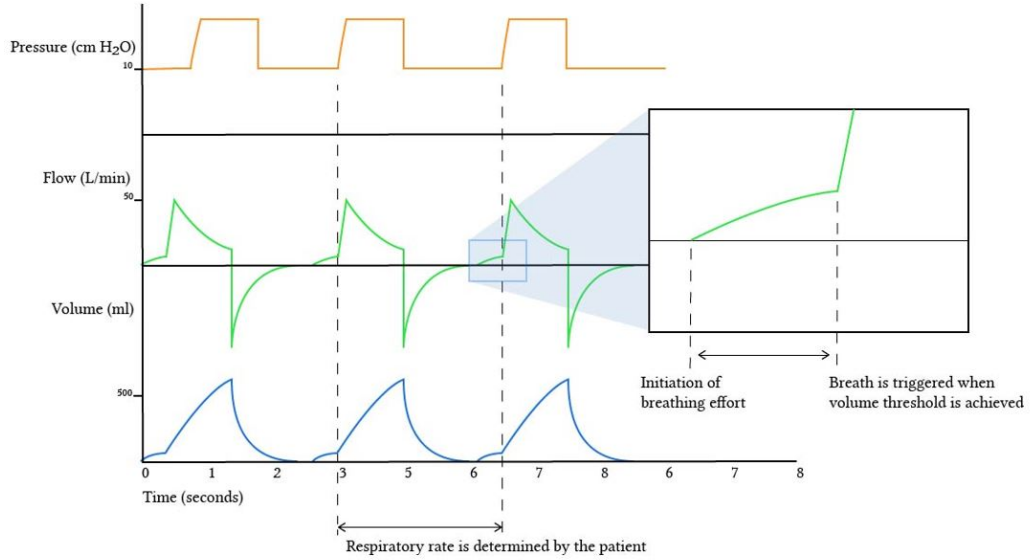
Over the duration of the patient's stay in the IUC, flow triggering appears to have some advantage. The trials of mechanical ventilation weaning which focused on important patient-centered outcomes (mortality, days off the ventilator) instead of the abstract surrogates (work of breathing, asynchrony) have found some benefit. Khalil et al (2015) compared flow (2 L/min) pressure

(2.0 cm H_2O) in a group of 100 ventilated patients; the flow trigger group appeared to get off the ventilator much faster. Admittedly, something is funny about the data - the difference in ventilator days was massive, 4.72 vs 8.18 days, and the pressure trigger group had a much higher mortality (44% vs 36%) which causes one to question whether bias was present, but the overall signal appeared to favour flow triggering.

Volume triggering

If one has pressure triggering and flow triggering, and the ventilator has pressure flow and volume waveforms, then surely there must also be volume triggering, one would logically say to oneself shortly before realising that such a thing would probably be completely pointless on philosophical grounds. Indeed, volume triggering is virtually unknown. It needs to be mentioned in a footnote here to satisfy the authors' need for completeness, but it plays minimal role in the operation of modern adult ventilators, and one would probably not be penalised for not mentioning it in the exam.

Consider this. Volume triggering is described by Chatburn (2012) as *"the starting of inspiratory flow due to a patient inspiratory effort that generates an inspiratory volume signal larger than a preset threshold"*. One must be reminded that under most circumstances a modern ventilator never measures volume directly, but rather calculates it from flow over time. In other words, with the inspiratory valve still giving some insufficient amount of bias flow, the patient must generate enough flow for the ventilator to detect this as a change in volume. So, if you have your ventilator measuring flow and then converting it into volume, then surely it would be easier (and more comfortable for the patient) to just omit that step and trigger breaths according to flow instead. By the same logic, any flow triggering is also technically volume triggering because some volume *must* change as the result of a change in flow. In summary, volume triggering would represent a sort of pointless duplication of flow triggering.



That conclusion wouldn't be completely accurate, but it appears to have been the conclusion of virtually all the ventilator manufacturers. Of the existing machines, the Drager Babylog appears to be the only ventilator which offers volume triggering as an option. According to this ancient operators' manual, the device offers ten trigger volume settings, ranging from about 0.02ml to 3ml.

Why? The main advantage seems to be the expectation that autotriggering should be reduced. When flow is divided by time to convert it into volume, much of the noise in the signal ends up being obliterated by the maths. Therefore, all the circuit condensation and cardiac oscillations are going to go unnoticed. This probably has implications in neonatology, where one might be ventilating somebody weighing 800g, with a tidal volume of 5 ml. With a flow trigger of 0.2 L/min, even the tiniest disturbance in the circuit could produce autotriggering. The Drager manual acknowledges that the ventilator measures flow and is nominally flow-triggered, but that "in order to reliably detect inspiration, and to avoid triggering a ventilation stroke as the result of interference signals, the patient must first breathe in a certain volume".

Searching the literature, one struggles to find any reference to the successful application of a volume-triggered mode of ventilation to adults, or a review of its physiological effects in infants. The term appears only in narrative review articles, the authors of which (like Chatburn, 2012, and Sassoon, 2011) were writing with the intent of being inclusive of every possible permutation of trigger mechanisms, for example for the purpose of classifying ventilator modes.

Neurally Adjusted Ventilatory Assist (NAVA)

Trainees of the modern era will likely never encounter this in their practice because of the decrease in its popularity. The NAVA method depends on a mechanical breath being triggered by a change in diaphragmatic EMG, detected by a properly positioned electrode array on a specially designed nasogastric tube. The tube must be positioned in precisely the right position, and when it is, the diaphragmatic EMG can be used not only to trigger breaths but also to proportionally assist the patient, adjusting the pressure volume and flow characteristics to better match the patient's inspiratory effort. Thus, a forceful diaphragmatic contraction produces a large EMG signal, which then recommends a deep breath with a fast inspiratory flow rate. The intensivist can then gradually decrease the proportion of the support, thereby weaning the patient off the ventilator.

This sounds wonderful and has several advantages which are widely deployed by the Getinge Group as propaganda to support the sale of their devices. An excellent example is this article by Skoro et al (2013) where the many merits of NAVA are listed:

- **Synchrony should improve,** as the NAVA catheter should only detect diaphragmatic EMG. Most forms of trigger dyssynchrony are related to the pneumatic events in the ventilator, i.e. somewhere somebody is either not generating enough of pressure or flow, or too much, or at the wrong time. NAVA is completely divorced from such crude gaseous phenomena, and should therefore be sensitive only to genuine respiratory efforts. It should also be faster (reducing the delay between effort and breath delivery), given that muscle contraction is sensed by the EMG electrodes long before any air is actually moved by the patient's diaphragm.
- **The ventilator becomes more informative** - Diaphragmatic EMG can be continuously monitored for diagnostic purposes using the catheter, even when not NAVA-ing. This has implications for such pathologies as Guillain-Barre and myasthenia gravis; one may be able to observe the gradual recovery of neurological function without ever actually examining the patient, or coming anywhere near them.
- **The support is more proportional:** as intensivists, we think we know

what ventilator settings the patient wants and needs on the basis of their clinical performance, blood gas biochemistry, chest Xray findings, the cleaner's comments, and so forth. NAVA proposes that we are wrong and that the patient should have more control over the amount of support they receive. With NAVA, the pressure and flow are adjusted every moment (16 ms to be precise) to better suit patient demand. This results in greater breath-to-breath heterogeneity but is much better tolerated.

- **The pressure level ends up being lower.** Because of the proportionality of support, you are not committed to using boring old square waveforms. As the result, the mean airway pressure is greatly reduced, as NAVA pressure waveforms are generally not square. This is promoted as a good thing (i.e. protective against ventilator-induced lung injury), and certainly it appears to be supported by some rabbit data (Brander et al, 2009)
- **It might be cheaper** because you wean them faster. A group of Maquet employees in a study paid for by Maquet published an economic analysis trying to convince the public of the cost savings (Hjelmgen et al, 2016). According to this literature, the 1.7 fewer days of mechanical ventilation would have cost $US 7886.

There are a few disadvantages to NAVA, which are worth being aware of.

- **Respiratory drive mechanisms need to be relatively intact.** NAVA makes assumptions about the way your brain commands ventilation and communicates with your diaphragm. If you have bilateral phrenic nerve paralysis, this method of triggering will not work for you. If your medulla is disabled and your respiratory drive is somehow affected (eg. by sedation), this spontaneous trigger is also ineffective (though in its defence so are all the other spontaneous trigger methods). If the neuromuscular junction is somehow diseased or disabled by drugs, again NAVA will not work. Conversely, if something is irritating the respiratory drive centres (eg. salicylate toxicity) the NAVA-triggered mechanical ventilator will dutifully help the patient hyperventilate.
- **The accuracy of the support relies on the nasogastric sensor position.** Obviously, that's not the most reliable feature of this process. The oesophagus is squishy, mobile, peristaltic, and potentially

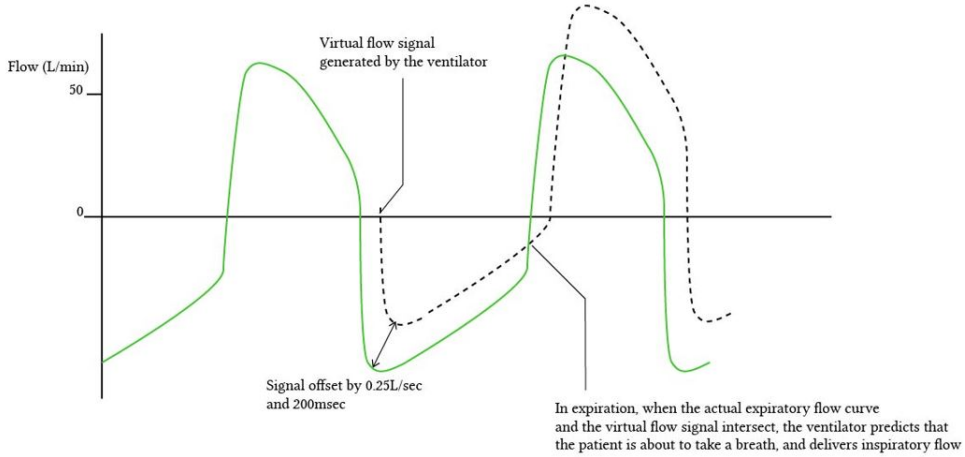
affected by some sort of disfiguring anomaly (like a hiatus hernia). These aspects make it difficult to prevent tube migration, to say nothing of the possibility that the patient may just pull it out in a fit of rage.

- **Obviously, nasogastric access cannot be contraindicated,** for example by trauma, rupture, surgery or something else in the mediastinum that would normally prevent you from inserting an NG tube.
- **There is no evidence that it improves outcomes.** Demoulle et al (2016) performed a multicentre RCT where they compared NAVA to PSV over the first 48 hours after coming off complete mandatory support. The primary outcome was likelihood of having to return to full mandatory support, and that was no different. Nor were the secondary outcomes (mortality, ventilator-free days, etc). NAVAed patients had a slightly lower chance of needing NIV following extubation, which was the only statistically significant finding. In spite of the fact that Maquet paid for the trial and sponsored the investigators, the group were forced to conclude that their device made no major difference in adults. Nor does it work any better in neonates (Rossor et al, 2017), though it must be said that there is no evidence of harm, and that the data at the moment is fairly sparse (only one trial made it into the Rossor meta-analysis).

Shape-signal triggering

Though this is another manufacturer-specific peculiarity, this needs to be mentioned as an alternative to all the other trigger modes, if only because is it sufficiently distinct from them by mechanism. If one wanted to read more about it, one would find the best explanation in Shape-signal triggering is essentially a method of predicting the next patient inspiratory effort by observing their expiratory flow waveform. When the patient's effort distorts this flow waveform, the ventilator assumes that a breath is being asked for. The precise level of "distortion" required for triggering is determined by superimposing the patient's own flow waveform on top of itself, with an offset value (in the Respironics Vision system, it is 0.25L/min and 200-300 msec). Given that inspiratory flows are often measured in tens of litres, 0.25L/min and

0.2 seconds are miniscule offsets; in the diagram below they have been greatly exaggerated for illustration purposes. In short, when the offset "virtual signal" is crossed by the patients' actual flow signal, the ventilator triggers a breath.



So, what would be the point of this? Well, it's apparently easier to trigger the ventilator in this manner. Priniakis et al (2002) demonstrated that 50% less effort was required to trigger the ventilator when compared to standard flow triggering (they compared it to a Drager Evita 4, flow-triggering at 2.0L/min). Predictably, "The flow waveform method of triggering was more sensitive to patient effort than the flow triggering, resulting in less ineffective effort but a greater number of auto-triggerings". One can envision an application for this system in situations where the patient would have some genuine trouble generating sufficient inward flow to trigger conventionally, but where their effort would be obvious from the ventilator waveform (eg. in significant bronchospasm). Vasconcelos et al (2013) used a similar proprietary method (Auto-Trak, by Phillips – because everything is cooler when it is misspelt). The comparison was in healthy volunteers and for some reason the control group were on a pressure trigger of 1.0 cm H_2O. Discomfort scores were statistically similar, as were many of the other variables. On the balance of evidence, one would have to conclude that these systems do not offer much advantage over conventional systems in terms of patient-ventilator synchrony or breathing effort.

Previous chapter: Control variables: volume and pressure

Next chapter: Limit (target) variables in mechanical ventilation

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